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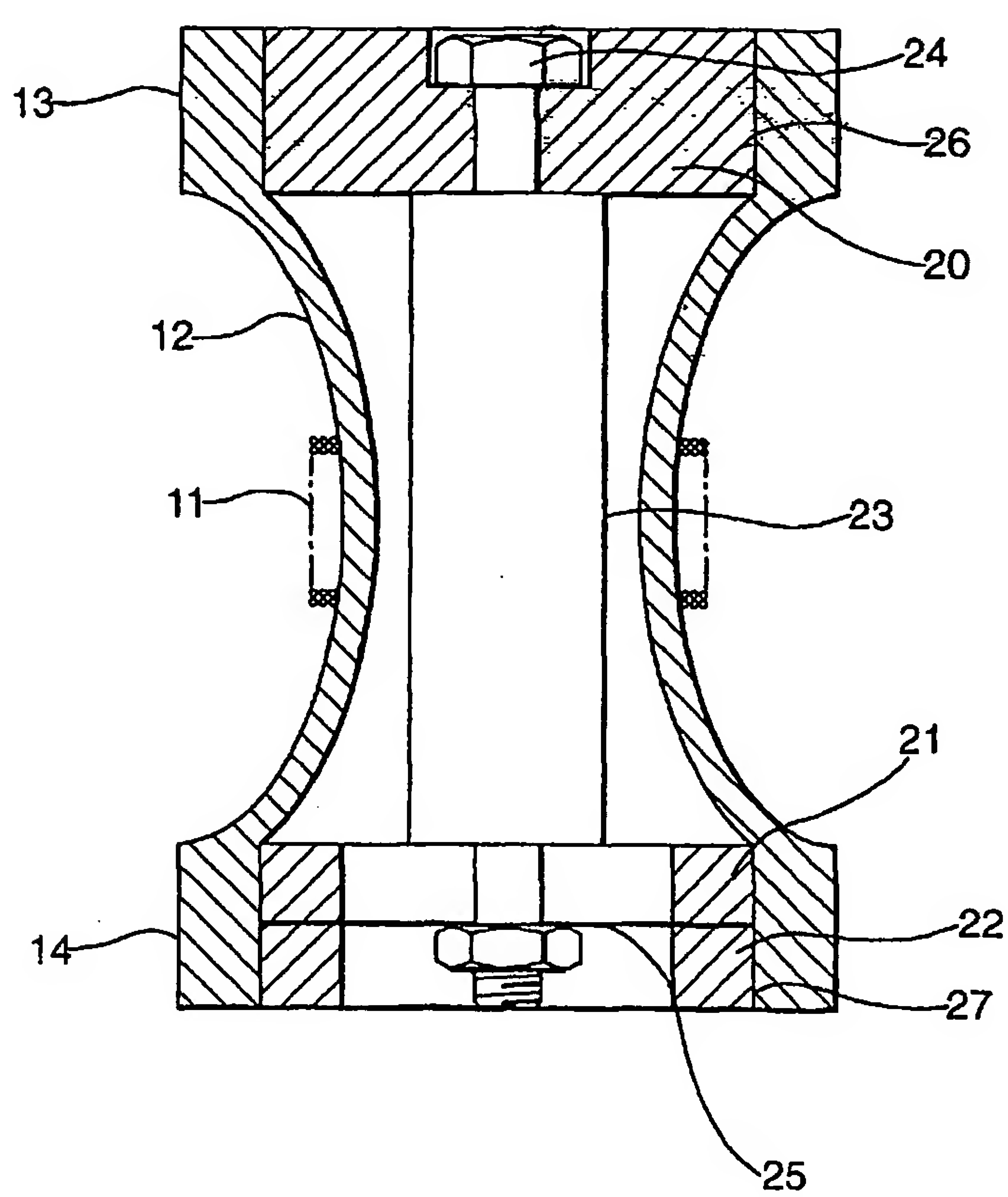
(54) Title: VIBRATION SENSOR



(57) Abstract: A vibration sensor for monitoring movement of a surface being a high responsivity accelerometer utilising optical fibre, or some other strain sensing method, mounted on a flexural casing (12), connected to a mass (23) within the casing, which is formed into an elliptically tapered concave cylinder, with a mass (23) depending from one end of it. The movement monitoring area is located by the other end of the device from the mass end. The invention can use optical fibre coils (11) wound around the structure at the mid point of the cylinder in a plane normal to the axis of the cylinder. The device can be used to detect seismic applications.

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VIBRATION SENSOR

This invention relates to a vibration sensor in the field of high responsivity accelerometers, in particular those operating using fibre optics as the interrogation and sensing medium. The word accelerometer is used to mean a device which can detect the acceleration of a body or structure. Such vibration sensors can be used to detect movement in seismic applications.

In the study of structures the monitoring of the physical characteristics of the structure is important; this is achieved using transducers. These transducers transform the change in the physical property to another change, which may be more easily understood or transmitted. A typical application of such transducers is in the monitoring of oil production, and can be used to measure such quantities as temperature, pressure, fluid flow and seismic signals. The field of oil production presents several major problems to the use of transducers, most of them being the response to a harsh environment.

Current art is dominated by the use of electrical devices; the survivability of these devices is severely limited due to the requirement of on-board electronic signal conditioning circuitry. These electronics require power and packaging to preserve them from a highly corrosive, vibrational and high pressure environment. The packaging and power requirements all lead to large bulky installations. The electronics must also be highly reliable so that retrieval of the sensor package is not required; this means that the electronics package will be correspondingly expensive. Multiplexing of these electronic devices leads to an increase in the unit mass and size.

In the higher temperature applications the conventional electronic accelerometers, which use the reverse piezo electric effect, experience reduced sensitivity when the Curie temperature is approached. This reduction in sensitivity can, in extreme cases, lead to complete nullification of the piezo electric effect, this is a non-reversible process. The fibre optic accelerometer has less sensitivity than piezo materials to temperature dependant physical properties, except when the device is heated to destruction, typically several hundred degrees centigrade, and is therefore relatively

unaffected by the temperature it is liable to encounter in the application of down hole oil field measurements.

Electrical signals are notoriously hard to transmit in oil production environments, the main problems being the insulation between signal lines and the degradation of connections. The transmission of the electrical signals are also prone to induced noise in a number of applications.

Seismic signals are traditionally measured using an electrical accelerometer aligned in the direction of interest. Most accelerometers are constructed using a mass-spring transducer mounted in a casing; the casing is in intimate contact with the surrounding medium in which the vibrations are propagating.

Optical interferometers are capable of measuring the acceleration, or displacement, of a structure with very high accuracy. Very small displacements of the fibre yield large variations in optical signal in the fibre. Fibre optic interferometer accelerometers have been designed to take advantage of this accuracy and they can exhibit fairly high responsivities and sensitivity. These prior art devices are based on the principle wherein one fibre of the interferometer is stressed by some means; the fibre may be fixed to some sort of mandrel or disc structure.

A number of these devices achieve high responsivity using a large mass or large dimensions; this means that the devices are unwieldy and difficult to use in the field. The majority of high sensitivity accelerometers use an active mass greater than 500 grams this can limit the frequency range in which the sensor can be used.

It is the objective of this invention to provide a vibration sensor which exhibits high responsivity and low threshold levels in the on axis orientation and low responsivity in the off axis direction, with low mass and volume.

Accordingly, the invention provides a vibration sensor for monitoring movement of a surface comprising a casing being a flextensional body having a first end and a second end and a central longitudinal axis between the two ends; the first end has fixably attached to it an axially extending mass, and the second end is located adjacent the surface to be monitored; a means for allowing axial movement of the

mass and for restraining non axial movement; and a means for measuring strain on the casing, resulting from movement of the second end which results from movement of the monitored surface.

The casing is advantageously concave between the first and second ends, and having one or more optical fibres coiled around the concave section of the casing for detecting non axial deviation. The casing may be cylindrical, with the concave portion of the casing being elliptically concave. The curve of the concave portion is a vibration sensor as previously disclosed in which the curve of the concave portion is a semi-ellipse such that it has a semi-major axis and semi-minor axis, with the major axis of the ellipse being parallel to and off set from the axis of rotation of the casing, such that the ends of the major axis are at a greater distance from the axis of rotation of the casing than the end of the minor axis. In particular the curve may be a semi-ellipse such that the length of the semi-major axis is twice that of the semi-minor.

A preferred version of the present invention provides a vibration sensor as previously disclosed in which the casing is longitudinally slitted to increase movement amplification, and hence greater responsivity.

A further advantageous aspect of the present invention provides a vibration sensor as previously disclosed in which the means for allowing the axial movement is a suspension diaphragm attached to the second end of the casing. This may have circumferential apertures which increase axial movement but still restrain movement in the non-axial direction.

A further aspect of the present invention provides a vibration sensor system comprising two or more vibration sensors, as disclosed herein, longitudinally attached together along the same axis. And the two vibration sensors can be attached to each other at the second end of the casing of each vibration sensor and fixably attached to an outer shell where the second ends of the two casings are attached. Or the two vibration sensors can be attached to each other at the first end of the casings and the two vibration sensors are attached to the outer shell by the second ends.

A further aspect of the present invention provides a vibration sensing system, comprising: a first plurality of vibration sensors according to a first aspect of the present invention; an electromagnetic radiation source and an electromagnetic radiation detector; said optical fibres of said first plurality of vibration sensors being arranged in optical communication with each other and with said electromagnetic radiation source and detector; said electromagnetic radiation source being operable to transmit an optical signal into said optical fibres of said plurality of vibration sensors; and said electromagnetic radiation detector being arranged to receive electromagnetic radiation output from said plurality of vibration sensors and to detect a variation in at least one predetermined property thereof.

The vibration sensors of the present invention are particularly well adapted to mounting in an array arranged optically in parallel or in series as a vibration sensing system. This makes them particularly adapted for use as seismic sensors. Preferably a vibration sensing system, comprising a first plurality of vibration sensors according to the first aspect of the invention; an electromagnetic radiation source and an electromagnetic radiation detector; the optical fibres of said first plurality of vibration sensors being arranged in optical communication with each other and with said electromagnetic radiation source and detector; said electromagnetic radiation source being operable to transmit an optical signal into said optical fibres of said plurality of vibration sensors; and said electromagnetic radiation detector being arranged to receive electromagnetic radiation output from said plurality of vibration sensors and to detect a variation in at least one predetermined property of said output optical signal. Advantageously the system could use a time division demultiplexer.

A still further aspect of the present invention provides a method of manufacturing a vibration sensor according to the first aspect of the invention comprising the steps of mounting the casing on a mandrel, comprising a central rod and having support members at each end; compressing the casing between the support members; passing the fibre through a resin bath; and winding the fibre around the shell.

Preferably the method includes: (i) passing an optical fibre through a reservoir of resin, such that a layer of resin coats said optical fibre, said optical fibre exiting said reservoir of resin via a needle, said needle being operable to position said optical

fibre above said disk and being arranged to allow a suitable amount of resin to coat said fibre; (ii) winding said resin coated optical fibre onto a flexural disk such that a spiral of optical fibre is attached to said disk by said resin and at least one end of said optical fibre is accessible for connection to external optical components; wherein said optical fibre passes out of said reservoir of resin via a needle.

It will be appreciated that the optical signal transmitted through the fibre optic sensor can take a variety of forms, and may for example be in the visible, ultraviolet, or infrared range. In preferred embodiments, the optical signal is an infrared signal. Further, it will be appreciated by those skilled in the art that the predetermined property of the optical signal which is varied in dependence on the received stimulus signal may also take a variety of forms, dependent on the construction of the fibre optic sensor, and for example may be phase, amplitude, polarisation, etc. In preferred embodiments, the predetermined property is phase.

It is further an object of this device to provide a linear response to acceleration when used with other strain sensing elements in place of the optical fibre. This is done by replacing the fibre with a piezoelectric material eg. PVDF (poly vinyl difluoride). This is a film which undergoes stresses which undergo the reverse piezoelectric effect generating a measurable potential difference.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a schematic of the finished device showing the shape of the device with the fibre coil;
Figure 2 shows a schematic cross section of the finished device showing an internal view of the accelerometer, showing the internal mass;
Figure 3 shows a schematic of the suspension diaphragm;
Figure 4 shows an alternative design for the guidance of the mass;
Figure 5 shows a schematic of a realisation of a plurality of the devices to achieve the sensitivities required, and to reduce the cross axis sensitivity;
Figure 6 shows an alternative schematic of a realisation of a plurality of the devices to achieve the sensitivities required;

Figure 7 shows a means of winding a fibre optic onto the disk according to an embodiment of the present invention;
Figure 8 schematically shows a plurality of vibration sensors arranged in series; and
Figure 9 shows a plurality of optical fibres arranged in parallel and in series.

As shown in Figure 1 the total device (10) consists of the cylinder (12) and the coil (11). The cylinder (12) is sliced into several staves aligned with the axis of the cylinder, in the manner of a barrel. The fibre coil (11) is wound around the narrowest part of the cylinder (12); this is to achieve the greatest amount of gain from the device. As shown in Figure 2 the cylinder (12) is constructed from a rigid, typically, plastic or metallic material in our preferred embodiment, but may be formed from any material with the required physical properties; it is machined such that there are both internal and external shapes. One end, the mobile end (13), of the cylinder (12) is machined to have an aperture (26) for an end cap (20) and the other end, the fixed end (14), having an aperture (27), is also manufactured to take parts (21, 22 and 25), where (21) is a threaded ring to provide a working surface for suspension diaphragm (25), and (22) is a clamping ring that holds (25) in contact with ring(21). Part (20) is the end cap from which the mass (23) depends; this is the moving part. At the other end of the cylinder (12) there is a suspension system (25), to prevent sideways motion but allow axial motion of the device.

As shown in Figure 3 the suspension diaphragm (25) is fabricated from a thin section of metal, in the preferred embodiment, with circumferential apertures (33), these circumferential apertures (33) leave thin sections of metal (30 and 31). When axial force is applied to the device (10) the inertia of the mobile end cap (24) and mass (23) will resist the motion. As the sides of the cylinder (12) are flexible the end cap (20) will move relative to the fixed end (14). Because of the shape-effects inherent in the design, the cylinder (12) will move in a plane normal to the axis of the cylinder (12). The fibre coil (11) is wound on to this part of the device (10). Because of the shape factor in the device there is mechanical amplification between the axial and the radial motion.

Figure 4 shows an alternative design for the mass (41) and the guidance system (40) for the mass. For this embodiment of the design the mass (41) and the end cap are now one and the same, the compliant spring is replaced with a sliding fitting. Holes

are manufactured into the guide (40) to allow flow of the surrounding fluid into and out of the enclosed volume in the device. These holes can be used to tune the resonant frequency and damping of the device.

In Figure 5, two devices (10) are arranged such that the ends from which the mass depends (13) are at the opposite ends of the compound device, the centre of this fixed to an outer casing (35). In the embodiment of the device the coils are arranged in push-pull mode, this will increase the responsivity by 6dB or by a factor of two. The masses may be mounted in the centre of the device with the other ends fixes to the casing, as in Figure 6.

The accelerometer consists of a rigid casing holding the accelerometer workings. The accelerometer itself is supported on one end and the mass is mounted on the other end of the accelerometer and aligned with the vibration direction. This device consists of an ellipse concave tapered cylinder cut into vertical staves, with a solid disc at the opposing ends. The cylinder is supported on one end and the mass fixed to the other end, fibres are wound in the plane normal to the axis of the cylinder around the narrow part of the cylinder. To limit the cross axis response of the device the free end of the mass is connected to the sidewalls through a diaphragm suspension unit, this diaphragm is machined such that it resists cross-axis movement whilst allowing on axis movement, or the means for allowing the axial movement is an axially aligned aperture closely fitting the mass.

This device is novel in that is uses a barrel stave geometry as a receiving device for vibration energy, typically in the form of structural or body vibrations. In this embodiment it is intended for the device to be used for detecting the vibrations present in a seismic measuring situation. This use does not limit the device to only that use and it can be used in other applications.

This is a high sensitivity vibration sensor based upon a fibre coil mounted on a barrel stave flextensional former. In one embodiment, the device consists of a single shell with a fibre coil arranged in intimate contact with the shell, this coil is wound on the shell in a plane normal to the axis of the cylinder. This accelerometer senses the motion in the direction of the axis of the cylinder by utilising the shape function of the geometry of the shell to change the orientation of the vibration and to achieve some

mechanical amplification. There are considerable savings in the time taken for fabrication of this accelerometer as the fibre coils are wound directly on to the shell. The shape of the shell self guides the fibres into the most sensitive position.

There is an inherent advantage in the use of this design in that there is a cavity in the construction and this can be used to house the mass. Furthermore, the mass can be inserted post-winding of the coil. With the mass completely enclosed in the flexible shell the overall size of the device can be reduced (in comparison with a typical geophone).

This design of optical accelerometer has an in built advantage in the area of multiplexing, in that the fibre coil can be accessed at each end. With both ends of the fibre accessible this device is ideally suited to time division multiplexing. The fibre has to be wound in such a manner that the fibre is free at both ends and therefore a number of these can be wound on to the various shells in one operation. That is the three components for the three axis measurements can be wound in one process, this will reduce the construction time and in some applications will be more efficient in terms of optical power.

When the net force acting in the direction of the long axis of the device changes from compressive to extensional the moment acting around the upper end of the ellipse changes both magnitude and direction. This means that to have a low distortion the device must be pre-stressed so that in normal use the net force acting along the long axis of the device must remain either compressive or extensional. The accelerometer exhibits low distortion when the device is pre-tensioned such that when the device is excited it stays in the linear displacement regime.

This device is preferably constructed in metal, or a plastic such as polyphenyline sulphide, slitted elliptically tapered cylinder with the optical fibre wound on to the surface of the cylinder. As the material properties of the glass and the metal/plastic will be minimally affected by the change in temperature that it is expected to encounter there will be no appreciable change in the responsivity of the device.

Figure 7 shows a method of manufacture and a means of winding a fibre optic onto the disk according to an embodiment of the present invention. The shell (12) maybe

manufactured by either machining from a solid section of material, or in the case of a polymeric material substrate, it maybe injection moulded. The second process being the preferable as the production cost for large numbers of items will be considerably reduced.

To build the barrel stave sensor the fibre needs to be wound around the shell(12), while the shell is held under compression. The sensor shell (12) is mounted on a mandrel that consists of a support (71), which fits into the chuck of the winding machine. On the support, there is a construction of two concentric disks (72), one of the disks provides a pressure plate and the smaller disk allows the shell (10) to be centred on the support (71). Projecting from the support (71) there is an axial threaded bar (74) which carriers a sliding plate (73), the shell being supported between each of these plates (72,73). Beyond the plate, there is a nut (75), this nut (75) serves a dual purpose, one is to hold the sliding plate securely against the shell (12). The other is to allow a pretension to be applied to the shell (12).

The fibre (78) passes through a resin bath (76) and a positioning needle (77) on the winding machine traversing arm. A length of fibre (78) is drawn thought the needle (77) a loop is passed around the shell (12). Then the excess is wound loosely onto the mandrel (71) to form the fly lead. The winding machine turns, drawing the fibre (78) through the resin bath (76) and the needle (77). When sufficient fibre has been added the winder is stopped and the trailing fly lead is drawn through and coiled about the former (71). To prevent any deformation of the fibre coil and to keep the resin on the fibre the shell is then slowly rotated until the resin has cured. The compression is also kept on until the resin has cured and the tension will be maintained.

Once the epoxy resin has cured then the device (10) can be assembled from the chosen parts. Care must be taken to not damage the fibre (78) as it exits the shell (12).

The Optical Fibre (78) used in an embodiment of this invention has a 6 micron core with an 80 micron cladding. However, other types of optical fibre could be used. The epoxy resin used must have a high modulus to transfer the strains from the shell (12) to the fibre (78).

Figures 8 and 9 illustrate possible array architectures. The multiplexing regimes used are Time Division Multiplexing (TDM) in the array of Figure 8 and both Time Division Multiplexing and Dense Wavelength Division Multiplexing (DWDM) in the architecture of Figure 9.

Figure 8 shows the individual seismic sensing device coils (63). The coils (63) are bracketed by couplers (61). Attached to one of the outputs of the coupler (61) is a mirror (62), the other output is connected to a sensing coil (63). These couplers (61) and mirrors (62) are so arranged that there is a reflector before and after each coil so that a pair of light pulses contained within the fibre are reflected from the mirrors (62). The first pulse is split by the first coupler (61) a portion of the pulse is reflected back and the rest is directed into the coil (63), this pulse is then split by the next coupler (61) a portion of the light is then reflected back from the mirror. At the same time the second pulse is being split by the first coupler (61) and one portion of the light is reflected back. The lengths of the fibres and the timing of the pulses are selected such that the second pulse returning from the first mirror and the first pulse returning from the second mirror coincide on the receiver at the same time. Changes in phase between the two signals can be used to detect changes in length and/or refractive index of the coil resulting from strains imposed on the coil.

Figure 9 shows a plurality of these serially connected strings of vibration sensors or seismic sensors connected in parallel. The strings of seismic sensors are multiplexed and connected in parallel, using DWDM architecture. Items 71 are Multiplex/Demultiplex units these isolate a single frequency from the source and direct it to the relevant Seismic sensing device string and then multiplex the signal back into the signal fibre.

In summary, embodiments of this invention provide a highly sensitive sensing device which exhibits a low cross-axis sensitivity and can be easily multiplexed using both time division and dense wavelength division multiplexing.

The invention may be embodied in other specific forms without departing from the essential characteristics thereof. The present embodiments are illustrative and not restrictive, the scope being determined by the appended claims and all equivalents.

CLAIMS

1. A vibration sensor for monitoring movement of a surface comprising:

   a casing being a flextensional body having a first end and a second end and a central longitudinal axis between the two ends;
   the first end has an axially extending mass fixably attached to it, and the second end is located adjacent the surface to be monitored;
   a means for allowing axial movement of the mass and for restraining non axial movement;
   and a means for measuring strain on the casing, resulting from movement of the second end which results from movement of the monitored surface.

2. A vibration sensor as previously claimed in claim 1 in which the mass extends axially from the first end towards the second end.

3. A vibration sensor as previously claimed in claims 1 or 2 in which the means for measuring strain is one or more coils of optical fibre around the casing.

4. A vibration sensor as previously claimed in which at least a part of the casing is concave between the first and second ends.

5. A vibration sensor as previously claimed in claim 4 in which the optical fibre is coiled round the narrowed part of the concave casing.

6. A vibration sensor as previously claimed in which the concave portion of the casing is elliptically concave.

7. A vibration sensor as previously claimed in claim 6 in which the curve of the concave portion is a semi-ellipse such that it has a semi-major axis and semi-minor axis, with the major axis of the ellipse being parallel to and off set from the axis of rotation of the casing, such that the ends of the major axis are at a greater distance from the axis of rotation of the casing than the end of the minor axis.

8. A vibration sensor as previously claimed in claim 7 in which the curve of the concave portion is a semi-ellipse such that the length of the semi-major axis is twice that of the semi-minor.

9. A vibration sensor as previously claimed in which the casing is provided with a plurality of longitudinal apertures between the ends of the casing.

10. A vibration sensor as claimed in claim 9 in which the apertures are slits extending parallel to the axis of rotation of the casing.

11. A vibration sensor as previously claimed in claims 1-10 in which the means for allowing the axial movement is an axially aligned aperture closely fitting the mass.

12. A vibration sensor as previously claimed in claims 1-10 in which the means for allowing the axial movement is a suspension diaphragm attached to the second end of the casing.

13. A vibration sensor as previously claimed in claim 12 in which the suspension diaphragm is provided with circumfirential apertures which increase axial movement but restrain movement in the non-axial direction.

14. A vibration sensor as previously claimed in claim 11 in which the mass is secured to a plate which is secured to the first end of the casing.

15. A vibration sensor according to any one of the preceding claims, said optical fibre being mounted such that both ends of said optical fibre are accessible for optical coupling to further optical devices.

16. A vibration sensor according to any one of the preceding claims comprising protective sheathing covering said optical fibres.

17. A vibration sensor system comprising two or more vibration sensors, as claimed in any previous claim, longitudinally attached together along the same axis.

18. A vibration sensor system as claimed in claim 17 where the two vibration sensors are attached to each other at the second end of the casing of each

vibration sensor and fixably attached to an outer shell where the second ends of the two casings are attached.

19. A vibration sensor system as claimed in claim 17 where the vibration sensors are attached to each other at the first end of the casings and the vibration sensors are attached to the outer shell by the second ends.

20. A vibration sensing system, comprising:

a first plurality of vibration sensors or sensor systems according to any one of claims 1 to 19;
an electromagnetic radiation source and an electromagnetic radiation detector;
optical fibres of said first plurality of vibration sensors being arranged in optical communication with each other and with said electromagnetic radiation source and detector;
said electromagnetic radiation source being operable to transmit an optical signal into said optical fibres of said plurality of vibration sensors; and
said electromagnetic radiation detector being arranged to receive electromagnetic radiation output from said plurality of vibration sensors and to detect a variation in at least one predetermined property of said output signal.

21. A vibration sensing system according to claim 20, where said first plurality of vibration sensors are arranged optically in series.

22. A vibration sensing system according to any one of claim 20 or 21, said sensing system further comprising a plurality of partial radiation reflectors, said plurality of partial radiation reflectors being arranged before and after each of said plurality of vibration sensors; wherein

said electromagnetic radiation source is operable to transmit a plurality of pulses into said first plurality of vibration sensors such that a pulse of radiation that is reflected back through one vibration sensing device by a reflector immediately after said vibration sensing device reaches said electromagnetic radiation detector at the same time as, and interacts with,

a subsequent pulse reflected by a reflector immediately before said one vibration sensing device;

said variations in said at least one predetermined property of said optical signal detected by said electromagnetic radiation detector being variations in phase.

23. A vibration sensing system according to claim 22, further comprising a signal processor including a time division demultiplexer, said signal processor being operable to process signals produced by said electromagnetic detector in response to said variations in phase and to isolate signals from individual vibration sensors using said time division demultiplexer.

24. A vibration sensing system according to any one of claims 21 to 23, further comprising:

a second plurality of vibration sensors arranged optically in series with each other, said second plurality of vibration sensors being arranged optically in parallel with said first plurality of vibration sensors; and

a first and second wavelength multiplex/demultiplex unit operable to isolate a single frequency; wherein

said electromagnetic source is operable to produce pulses of radiation at first and second frequencies and said first and second wavelength multiplex/demultiplex units are arranged such that pulses of said first frequency are transmitted from said source to said first plurality of vibration sensors and pulses of said second frequency are transmitted from said source to said second plurality of vibration sensors.

25. A vibration sensing system according to claim 24, further comprising at least one further plurality of vibration sensors and at least one further wavelength multiplex/demultiplex unit, said at least one further plurality of vibration sensors being arranged optically in parallel with said first and said second plurality of vibration sensors; wherein

said electromagnetic source is operable to produce pulses of radiation at first, second and at least one further frequency and said at least one further multiplex/demultiplex unit is arranged such that pulses of said at

least one further frequency are transmitted from said source to said at least one further plurality of vibration sensors.

26. A vibration sensing system according to claim 20, wherein said first plurality of vibration sensors are arranged optically in parallel.

27. A method of manufacturing a vibration sensor according to any one of claims 1-15 comprising the steps of:

mounting the casing on a mandrel, comprising a central rod and having support members at each end;
compressing the casing between the support members;
passing the fibre through a resin bath; and
winding the fibre around the shell

28. A method of manufacturing a vibration sensor according to claim 27 wherein:

the optical fibre passes through a reservoir of resin, such that a layer of resin coats said optical fibre, said optical fibre exiting said reservoir of resin via a needle, said needle being operable to position said optical fibre above said sensor and being arranged to allow a suitable amount of resin to coat said fibre.

29. A method of manufacturing a vibration sensor according to claim 27 or 28 wherein:

winding said resin coated optical fibre onto the sensor shell such that a spiral of optical fibre is attached to said casing by said resin and at least one end of said optical fibre is accessible for connection to external optical components.

30. A method of manufacturing a vibration sensor according to any of claims 27 to 29 wherein:

the shell is slowly rotated until the resin has cured after the fibre has been wound around the shell.

31. A vibration sensor, substantially as hereinbefore described with reference to the accompanying drawings.

32. A vibration sensing system, substantially as hereinbefore described with reference to the accompanying drawings.

33. A method of manufacturing a vibration sensor, substantially as hereinbefore described with reference to the accompanying drawings.

Fig.1.

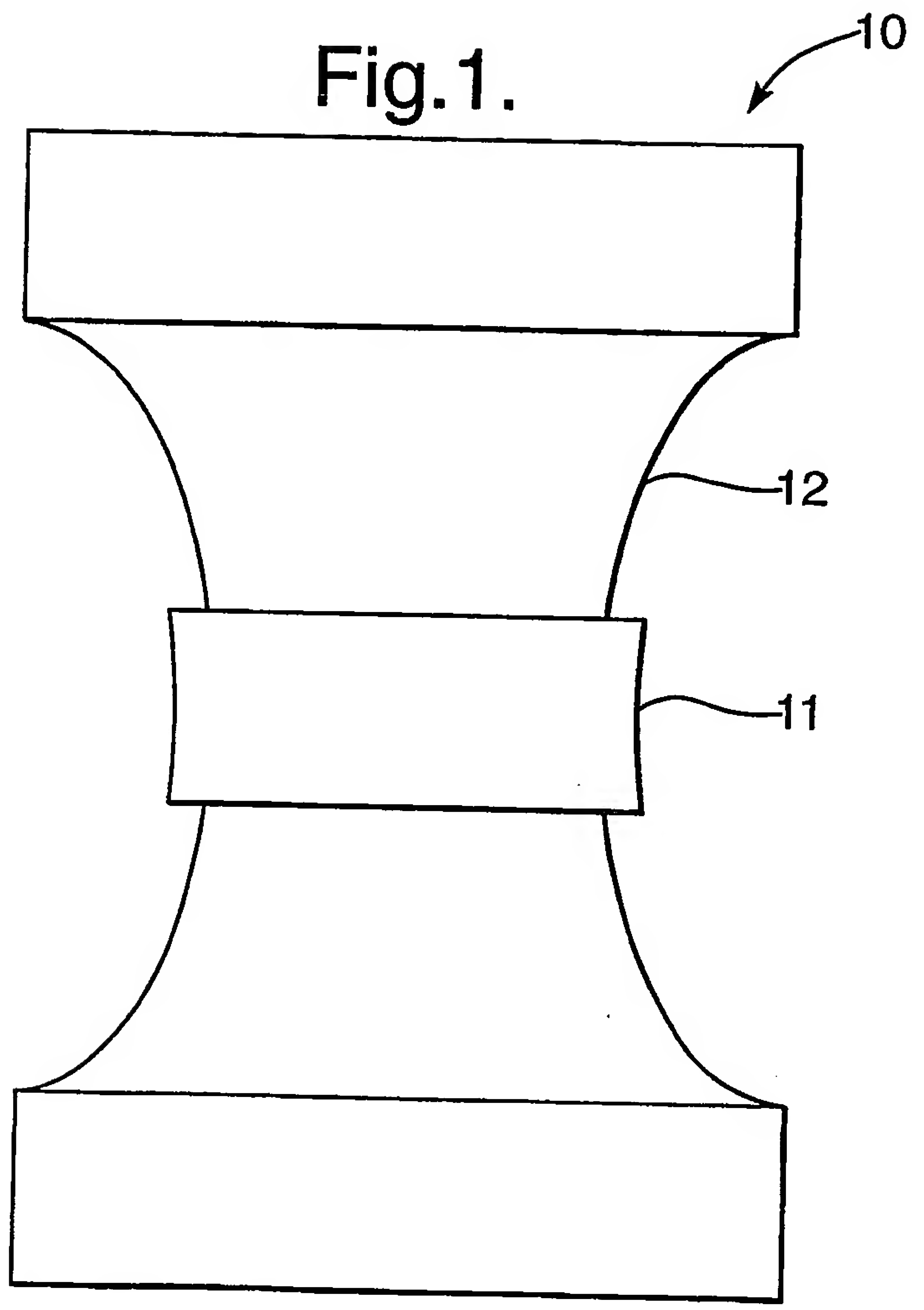

Fig.2.

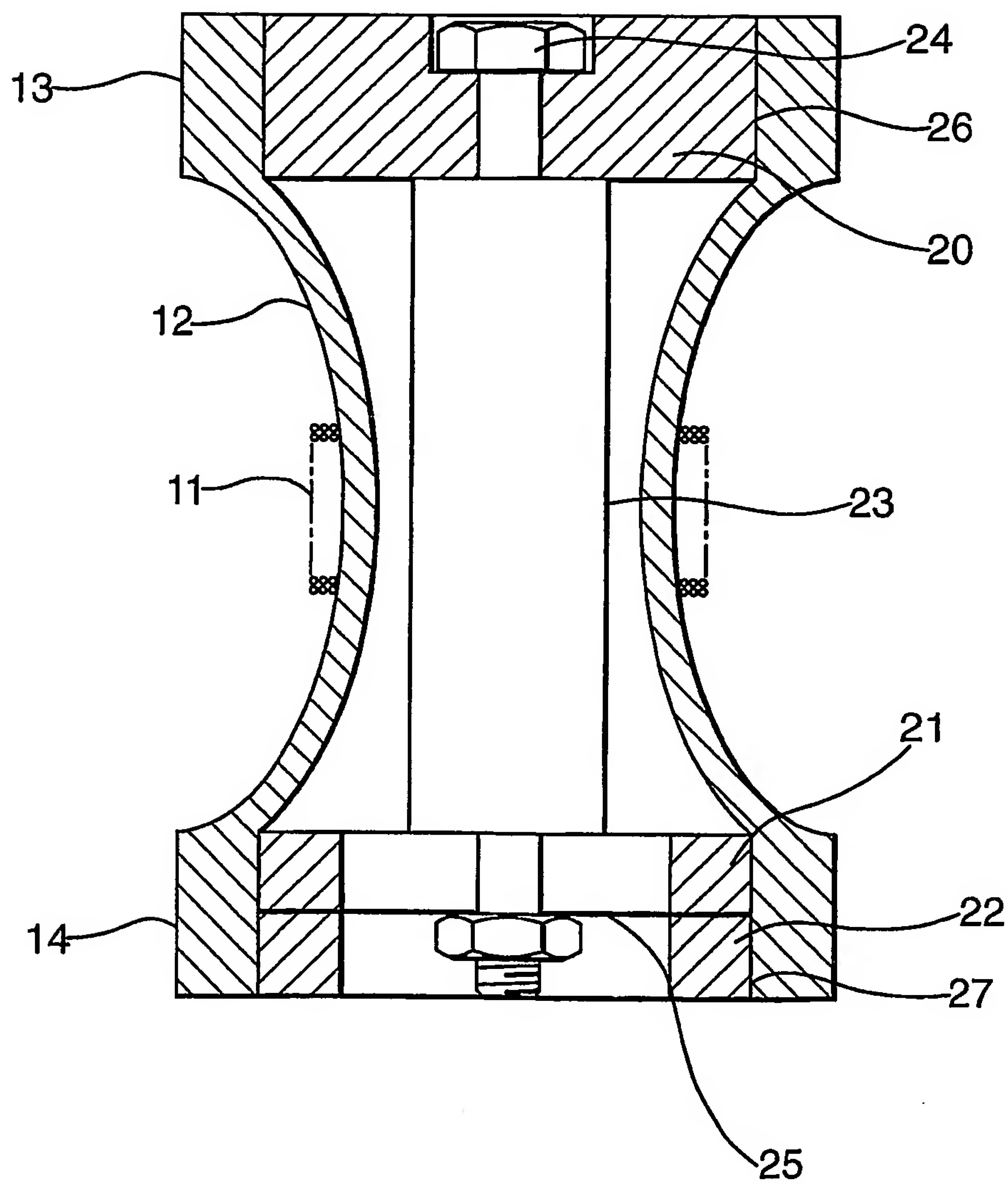

Fig.3.

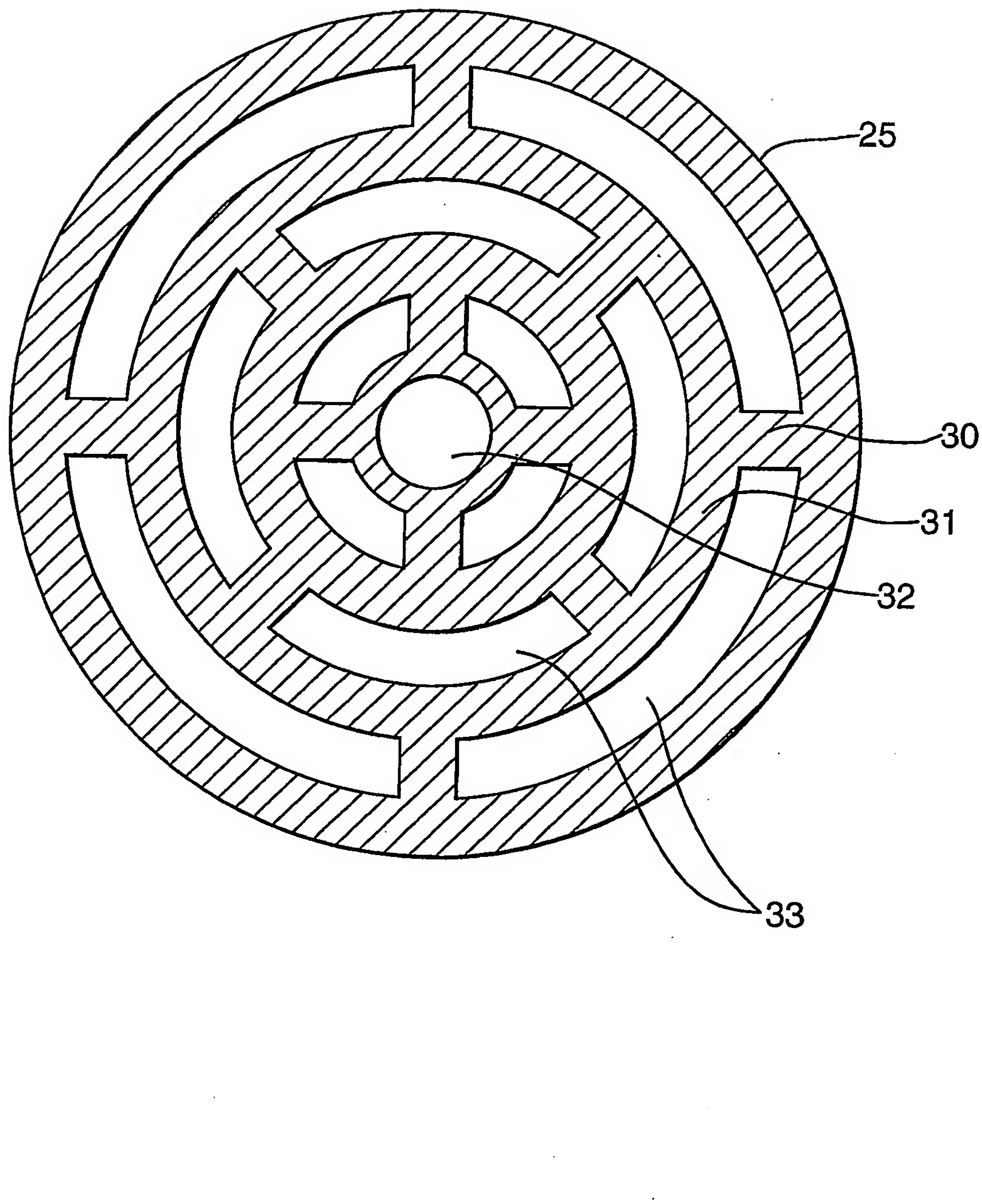

Fig.4.

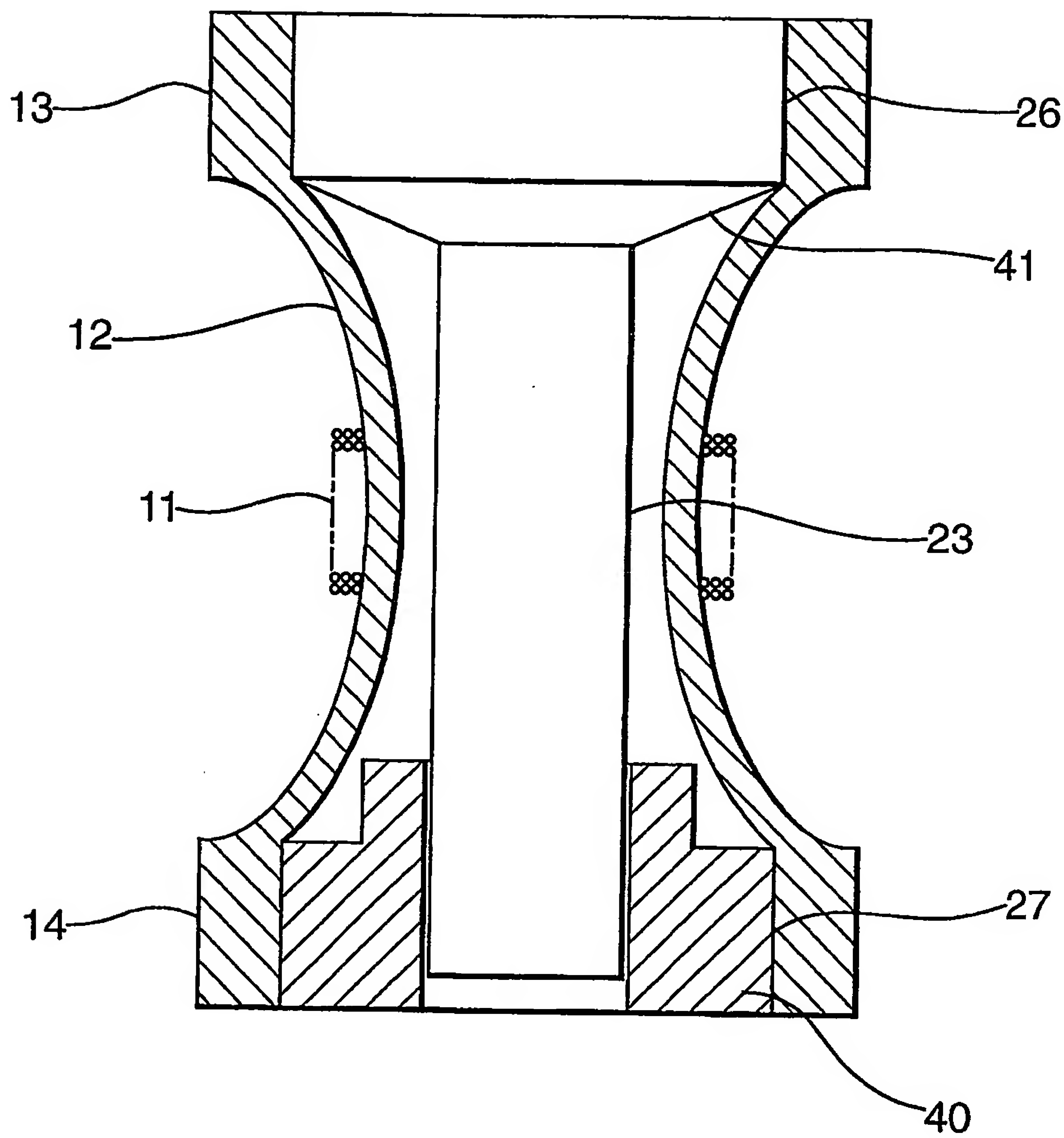

Fig.5.

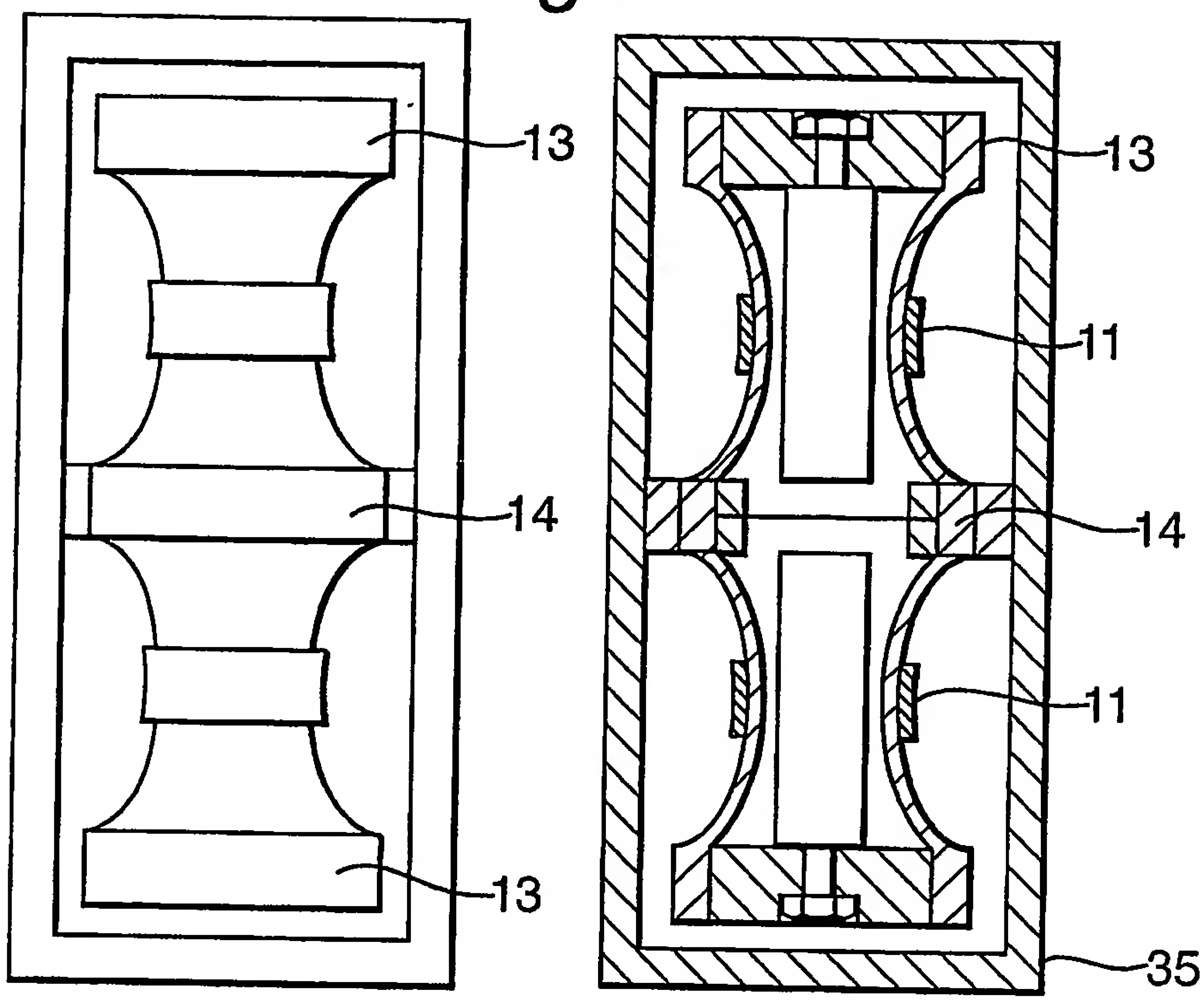

Fig.6.

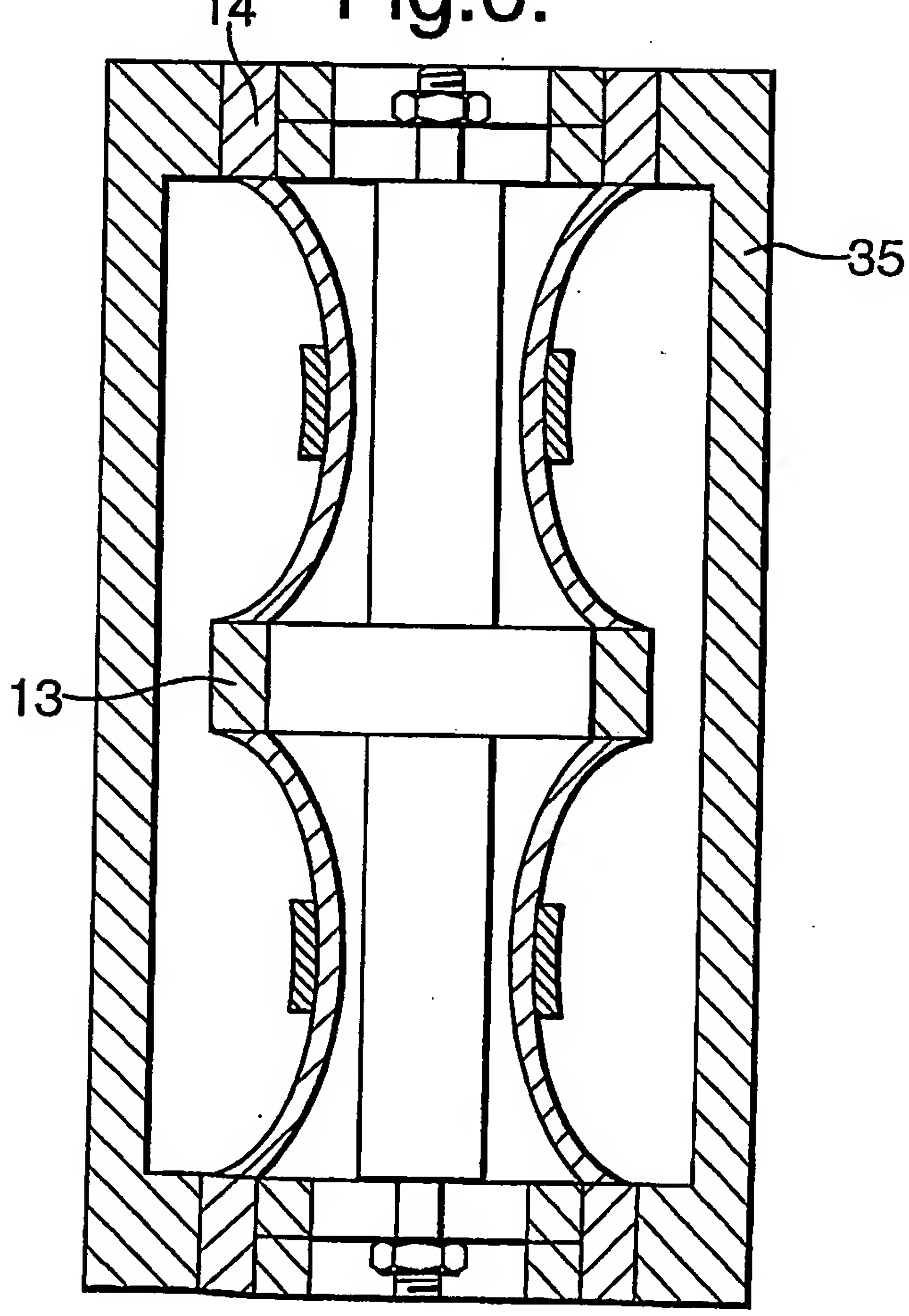

Fig.7.

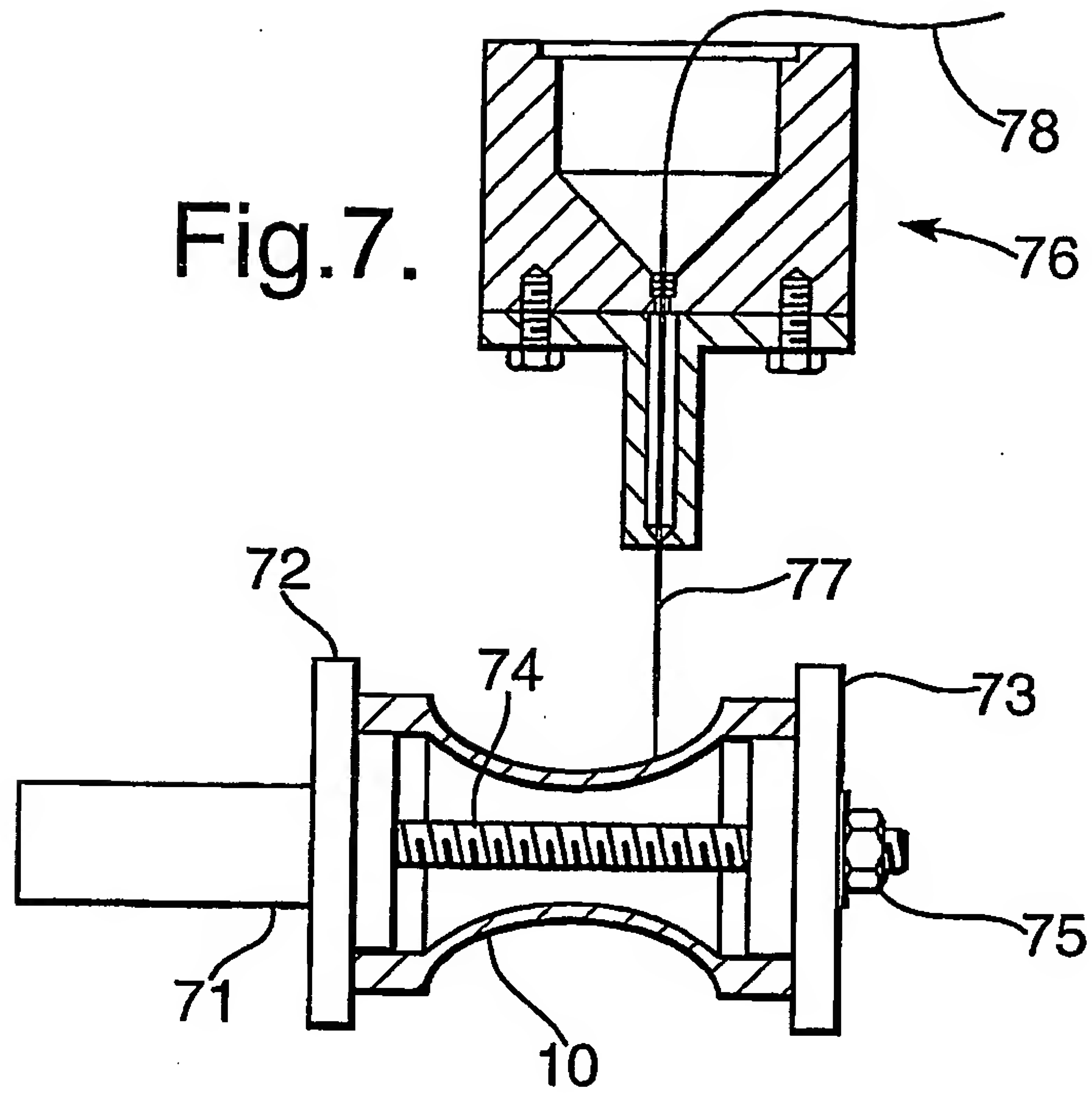

Fig.8.

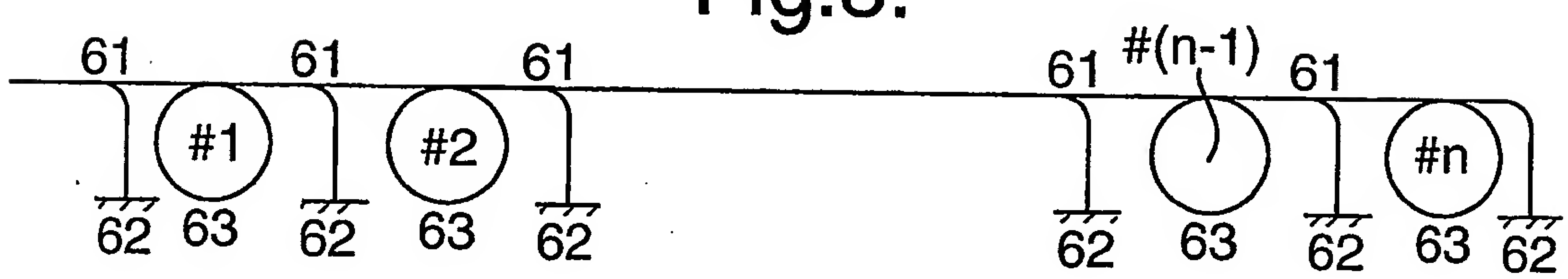

Fig.9.